Precambrian Metasediments of the Pine Creek Area,
Gilpin County, Colorado

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INTRODUCTION

For many years, high-grade metamorphism was in effect a geological "iron curtain" past which it was nearly impossible to see. This was especially true for metasediments; relatively few attempts were made to discover the nature of the sedimentary antecedents of rocks such as gneisses and schists of the amphibolite facies. However, recent progress in both metamorphic and sedimentary petrology has made such investigations practical, as shown by the work of Engel and Engel (1958), O'Connor (1961), and Hopson (1964), among others. This paper presents the results of a study of the Precambrian paragneisses and schists in a small part of the Front Range, and a discussion of the sedimentary rocks from which they may have been formed. The tectonic implications of the inferred pre-metamorphic history of this area will also be explored.

Acknowledgments

This paper is based upon the writer's Ph.D. thesis (Lowman, 1963). The project was suggested by Drs. E. E. Wahlstrom and P. K. Sims, both of whom contributed greatly to its completion. The writer benefited from many discussions in the field with other members of the U. S. Geological Survey engaged in mapping the Central City $7\frac{1}{2}$ minute quadrangle, of which the Pine Creek area forms the northern portion.

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Previous Work

A complete bibliography of literature concerning the Pine Creek area is given elsewhere (Lowman, 1963). The two most important recent papers are by Tweto and Sims (1963) and Moench, Harrison, and Sims (1962).

GENERAL GEOLOGY

The Pine Creek area is underlain by a large variety of igneous and metamorphic Precambrian rocks intruded by numerous Tertiary dikes and the Apex stock (Fig. 2). In the writer's original work, and in this paper, the focus is almost entirely on the Precambrian rocks and structures.

The most abundant Precambrian rocks are the metasediments which are the subject of this discussion, and which are described in detail separately. They are intruded by granodiorite considered equivalent to the Boulder Creek granite (Lovering and Goddard, 1950) and by a probably-related quartz diorite which grades locally into pyroxene gabbro. Both these Precambrian igneous rock types are associated with abundant pegmatite dikes.

The Precambrian structure (Fig. 3) is dominated by a linked syncline and anticline, both plunging to the north and slightly overturned to the west. Smaller structures include numerous folds and mineral lineations reflecting the major structures. A detailed description of these in the Central City district, which applies well to the Pine Creek area, is given by Moench, Harrison, and Sims (1962).

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PRECAMBRIAN METASEDIMENTS

Petrography

Biotite-Quartz-Plagioclase Gneiss

This rock type, with its sillimanitic and garnetiferous varieties, is estimated to comprise about 60% of the total stratigraphic thickness of the Precambrian metasedimentary rocks in the Pine Creek area. It is interlayered, on all scales, with other metasediments, and frequently migmatized.

The biotite-quartz-plagioclase gneiss is dark- to light-gray, fine-grained, and generally foliated although occasional hand specimens and outcrops are essentially massive. Its typical appearance is shown in Figures 4 and 5.

In thin section, the fabric of the biotite-quartz-plagioclase gneiss is typically crystalloblastic, and all varieties show well-defined foliation under the microscope. Poikiloblastic fabric is common. Almost all thin sections show some sericitization, and occasionally alteration of biotite and garnet to chlorite.

Modes are presented in Table 1. Descriptions of individual minerals were given in the thesis (Lowman, 1963).

Microcline-Quartz-Plagioclase Gneiss

This is the second most abundant metasedimentary rock type, comprising about 35% of the total stratigraphic column in the area. It occurs in several thick discrete layers, as in the Central City area, (Moench, Harrison, and Sims, 1962), and also as numerous small lenses and layers in the biotite-quartz-gneiss. In a few places, the microcline- and biotite-quartz-plagioclase gneisses grade into each other.

The microcline-quartz-plagioclase gneiss is fine-grained, buff or gray on weathered surfaces, and usually foliated. Typical outcrops are shown in Figures 6 and 7.

The fabric in thin section is typically crystalloblastic. Evidence of grain crushing is abundant, much more so than in the biotite-quartz-plagioclase gneiss. Microcline gneiss in a broad zone extending south from Dakota Hill (Fig. 2) has a distinctive augen structure, both in hand specimen and thin section.

Modes of the microcline-quartz-plagioclase gneiss are presented in Table 2.

Amphibolite and Lime-Silicate Gneiss

These two rock types occur as thin layers and lenses in the biotite-quartz-plagioclase gneiss and rarely in the microcline-quartz-plagioclase gneiss. They commonly occur together and in a few places grade into each other, suggesting a close genetic relationship. Typical outcrops are shown in Figures and a modal analysis is presented in Table 3.

Petrology

Metamorphism

Mineral assemblages of the microcline gneiss, biotite gneisses, and amphibolite are characteristic of the sillimanite-almandine-orthoclase subfacies of the almandine-amphibolite facies (Turner and Verhoogen, 1960). Local assemblages do not belong to this subfacies;

for example, almandite is partly altered to chlorite in some specimens, and epidote and clinozoisite occur in the lime-silicate gneiss. However, it appears that these occurrences represent localized retrograde metamorphism. Subject to such exceptions, most of the metasediments evidently formed under equilibrium conditions, as shown by their general similarity of mineralogy and of mineral composition.

Chemical changes during the formation of the Pine Creek metasediments are believed to be limited to the loss of volatile components (H_2O, CO_2) and the addition of silica and alkalis during migmatization.

The gradational and interfingering contacts between the microcline gneiss and the biotite gneisses, together with the granitic composition of the microcline gneiss, suggest the possibility that this unit may be metasomatic. However, several lines of evidence indicate that this is not so. First, the field relations of the microcline gneiss are unlike those expected of metasomatic granites (see, for example, Wahlstrom, 1950); instead of forming a fringe around a granitic core, the microcline gneiss occupies what seems to be a normal position in the metasedimentary sequence, forming interlayered tabular and lenticular bodies. Furthermore, there are no systematic changes along strike or dip suggesting nearness to a center of granitizing fluids. Finally, there are few if any of the usual mineralogic criteria of granitization, such as dents du cheval, schlieren of partly replaced gneiss, and zircon overgrowths (Eckelmann and Poldervaart, 1957).

This evidence against a metasomatic origin of the microcline gneiss is of interest not only because of its importance to the present discussion, but also because it demonstrates that some of the field relations commonly interpreted as metasomatic may actually be stratigraphic- a possibility suggested by Turner and Verhoogen (1960, p. 375).

The biotite and microcline gneisses are believed to be formed from sedimentary rather than igneous rocks for several reasons discussed in detail in the thesis. First, they are consistently concordant on all scales with metamorphic rocks, such as the lime-silicate gneisses, and with layers of sillimanite whose sedimentary parentage is unquestioned because of their composition. In addition, there appear to be all gradations between the various metamorphic rocks (excluding foliated syntectonic igneous rocks such as the granodiorite). Finally, the zircons of the microcline gneiss are uniformly rounded, in contrast with the angular grains described by Callendar and Folk (1959) from pyroclastics of the Gulf Coast.

Sedimentary Antecedents

The nature of the pre-metamorphic sedimentary rocks which later became the microcline and biotite gneisses can be inferred from two main characteristics of the present metamorphic rocks: texture and composition.

All the major metasedimentary rock types of the Pine Creek area are medium- to fine grained, with crystals generally well under 1 mm in the greatest dimension. Thin section examination shows that this small grain size is not the result of cataclasis. This, coupled with the fact that Precambrian conglomerates in nearby parts of the Front Range have survived high-grade metamorphism, suggests that the pre-metamorphic antecedents of the Pine Creek rocks were no coarser grained than they are. Any change in grain size during metamorphism was probably in the direction of increasing coarseness, so that the original rocks were probably fine-grained sediments. Similar reasoning has been used by Engel and Engel (1953b) to deduce the texture of pre-Grenville rocks in the Adirondacks.

It seems likely that the parent sedimentary antecedents of the Pine Creek metamorphic rocks formed layers ranging from a few hundred feet down to a few inches. This is inferred from the existence of layers of contrasting mineralogy with similar thicknesses.

The most useful criteria for establishing the nature of the pre-metamorphic rocks are their chemical compositions. These can be used, of course, only if there have been no major chemical changes during metamorphism; as mentioned previously, this seems to have been true for most of the rocks. Therefore, a comprehensive effort was made to use compositions to infer the nature of the original sediments.

Chemical compositions of the main rocks types in the Pine Creek area were computed from the modes. The methods and precautions against error are described in the thesis; the method was essentially that given by Wahlstrom (1950). It is believed that chemical compositions computed this way are accurate enough for the purpose of this investigation, especially if attention is focused on the major oxides: SiO_2, Al_2O_3, Na_2O, K_2O, and CaO.

A comparative tabulation of the chemical compositions of the Pine Creek rocks and possibly similar sedimentary rocks is presented in Table 4.

It is apparent from this comparison that several of the sedimentary rock types might be suitable antecedents for the biotite and microcline gneisses; these include the subgraywackes, Russian platform sandstone, the Mississippi delta silt, and if we consider SiO_2 content alone, Middleton's average eugeosynclinal sandstone. The last, however, can be eliminated from consideration because of its high soda/potash ratio - a characteristic of many eugeosynclinal sediments.

The most plausible parent rock would seem to be a composite of the average subgraywacke, Russian platform sandstone, and Mississippi delta silt. In view of the range of compositions encountered in each rock type and the relatively small number of analyses, there is no good reason to pick any one of these as the analogue of the original Pine Creek sediments. It is therefore suggested that the parent rocks were sedimentary rocks similar to these three types in texture and composition, consisting of interlayered silts and sands, to which the collective name "feldspathic subgraywacke" (Folk, 1954) might be given. The microcline gneiss was probably formed from a more arkosic sediment than were the biotite gneisses.

This suggestion is supported by the fact that the subgraywackes, Mississippi delta silts, and probably the Russian platform sands are essentially similar, not only in texture and composition, but in depositional environment and tectonic setting. They are generally the product of paralic (interfingered marine and continental) sedimentation on the continental platform at a considerable distance from orogenic belts (Pettijohn, 1957).

The nature of the antecedents of the amphibolites and lime silicate gneisses was not studied in detail, because it is not possible to compute reliably the chemical composition of these rocks from the modes. However, it seems likely that a limey sandstone might have been the precursor of the lime-silicate gneisses, which are high in quartz. The amphibolites are frequently associated with and in places grade into the lime silicate gneisses. This relation suggests a sedimentary rock, such as a limey shale, rather than basic igneous rocks or sediments derived from such.

Tectonic Implications

A number of tectonic inferences can be drawn from the probable petrography of the pre-metamorphic sedimentary rocks. One of the most obvious of these is that the Pine Creek metasediments do not represent a eugeosynclinal sequence. This is inferred not only from the calculated chemical compositions, but from the scarcity of metavolcanics such as amphibolites. Additional evidence comes from the absence of graded bedding typical of eugeosynclinal graywackes; that such structures can survive high-grade metamorphism has been demonstrated by O'Connor (1961) and Garawecki (1963) in the Ft. Collins area, and by Hopson (1964) in the Baltimore area, but nothing resembling it was found in the biotite and microcline gneisses.

The compositional and structural evidence, then, point to a cratonic setting, which might be considered an exogeosyncline (Kay, 1951).

To this should be added the probability that the Pine Creek rocks overlie a considerable thickness - perhaps 20 kilometers or more - of crustal rocks approximating granite in composition (Birch, 1951). Taken together, these relationships indicate strongly that the Pine Creek sedimentary sequence does not represent a lateral increment to an accreting continent, as proposed for other areas by Wilson (1954) and Kay (1951), since such are considered to be ensimatic eugeosynclines. Any continental growth would be essentially vertical accretion.

The picture presented here, then, supports the suggestions by Engel (1963) and Gastil (1958) that continental growth involved considerable overlap, and was not the primarily concentric process implied by the earlier theories. In particular, the results of this study indicate that, as Engel suggests, the Churchill (age about 1.8 billion years) and probably the Superior-Wyoming (age about 2.5 billion years) age provinces are larger, underlying the Pine Creek area, than would be indicated by exposed rocks (Engel, 1964, Fig. 3).

An interesting tectonic problem is uncovered by the work described here. The rocks of the Pine Creek area do not seems to be a eugeosynclinal sequence, nor do similar metamorphic rocks to the south (Lowman, 1963), such as those mapped by Wahlstrom and Kim (1959) and Koschmann (1960) (Fig. 1). On the other hand, O'Connor (1961) and Garawecki (1963) have demonstrated the eugeosynclinal parentage of pre-Silver Plume granite metamorphic rocks in the Ft. Collins area, whose relative age is apparently about the same as those of the Pine Creek metasediments. It is worth inquiring, then, why two such unlike tectonic assemblages are so close together.

Perhaps the most obvious answer is that one or both assemblages represent localized depositional conditions. This explanation, attractive because of its simplicity, cannot be evaluated without much more detailed information about the petrography of Precambrian rocks in a wide surrounding area.

A more exotic possibility is suggested by the recent studies of Fuller (1964) and Gillilland (1962). Both find evidence - Fuller in magnetic surveys, and Gillilland in regional structures - that the E-W Mendocino fault extends halfway, or farther, across North America at about the 40th parallel. The continuation has not, of course, been geologically mapped, and must be Precambrian in age. If there was considerable transverse displacement on such a fault, it might have brought the Ft. Collins and Pine Creek rocks together. Existing geological maps, however, show no evidence of such a fault in the exposed Precambrian rocks, nor is there a series of Laramide intrusions like the Front Range mineral belt which might mark its site. It seems worthwhile to consider this possibility as a very speculative working hypothesis, nevertheless, whose validity might be checked by further Precambrian field work between the Pine Creek area and Ft. Collins.

TABLE III

Mode of Amphibolite (Volume per cent)

Specimen Number	372
Quartz	10.2
Hornblende	69.0
Plagioclase	13.0
Biotite	1.2
Muscovite	4.1
Epidote	1.4
Apatite	0.4
Magnetite	0.6
Sphene	tr
Sericite (incl. muscovite)	tr
Total	100.0
Number of sections	2
Total measurement area	1020 mm^2
Total number of points	2400
IC Number	115
Plagioclase composition	An_{62}

Field Occurrence - Outcrop sample from lens 7 feet thick in microcline gneiss on ridge south of N. Clear Creek, 1/2 mile west of Pine Creek.

TABLE I

Modes of Biotite-Quartz-Plagioclase Gneisses (volume per cent)

Specimen Number	432	536A	709	710B	711	712
Quartz	53.8	26.5	60.0	53.0	48.1	67.7
Microcline					12.3	1.8
Plagioclase	7.5	47.1	13.6	19.4	4.8	6.2
Biotite	26.8	21.0	17.7	23.5	22.9	16.5
Chlorite	0.3			0.8	0.1	
Muscovite	0.1	0.3	0.7	0.1	0.5	0.6
Sericite	tr	tr	tr	tr	tr	tr
Sillimanite	10.0		6.6	tr	10.3	6.9
Garnet				1.3		
Magnetite	1.5	5.0	1.3	1.9	0.9	0.3
Zircon	tr	tr	tr	tr	tr	tr
Sphene	tr					
Total	100.0	99.9	100.0	100.0	99.9	100.0
Number of Sections	2	2	2	2	2	2
Total Measurement area (mm^2)	1200	1200	1020	1290	1350	1600
Total Number of Points	4100	4100	2500	4300	3400	3500
IC Number	over 130	94	over 110	130	over 130	over 130
Plagioclase Composition	An_{25}	An_{48}	An_{29}	An_{28}	An_{30}	An_{30}
N_z, biotite	1.635	1.712	1.646	1.638	1.638	1.642

Notes on field occurence on next page.

TABLE I
(Continued)

Field Occurence of Analyzed Specimens

#432 - Outcrop sample of sillimanitic biotite gneiss, about 50-80% migmatized, from east end of Pile Hill at 10,800 feet. Analysis is of unmigmatized portion.

#536A- Outcrop sample of massive, unmigmatized biotite gneiss from ridge 1/4 mile southwest of American City at 10,525 feet.

#709 - Outcrop sample of biotite gneiss, about 50% migmatized, from roadside, north side of North Clear Creek 3/4 mile east of intersection with road to Central City. Analysis is of unmigmatized portion.

#710B- Exposure sample of massive biotite gneiss from roadside, north side of North Clear Creek 1 1/4 miles west of intersection with Rt. 119.

#711 - Outcrop sample of unmigmatized biotite gneiss from roadside, north side of North Clear Creek 1 mile west of intersection with Rt. 119.

TABLE II

Modes of Microcline-Quartz-Plagioclase Gneiss (Volume %)

Specimen Number	350C	472	623A	623B	627	629	666	683B	697	704
Quartz	27.4	28.2	28.6	25.1	24.8	26.5	28.8	32.3	24.9	24.4
Microcline	17.6	25.0	32.3	28.3	21.0	22.4	41.9	19.4	32.9	4.3
Plagioclase	49.5	42.2	36.0	40.4	38.8	47.1	26.0	42.3	35.7	61.2
Biotite	1.6	1.9	2.2	4.2	14.0	1.0	2.4	4.9	4.8	7.8
Chlorite	0.3	1.1	0.2			0.2		0.4	0.2	0.1
Muscovite	0.5	0.2	0.4	1.1	tr	0.7		0.4	0.2	0.1
Sericite	tr	tr	tr	tr	tr	tr	tr		tr	tr
Magnetite	1.6	1.4	0.1	0.6	1.3	2.0	0.7	0.8	1.3	2.2
Pyrite	tr								tr	
Garnet	1.8		0.1	0.2	tr		tr			tr
Zircon	tr	tr		0.1	tr	tr	tr	tr	tr	tr
Sphene		tr			tr					tr
Total	100.2	100.0	99.9	100.0	99.9	99.9	99.9	100.1	99.8	100.0
Number of sections	2	2	2	2	2	2	2	2	2	2
Total measurement area (mm^2)	1200	1300	1170	1100	1140	1170	1300	1190	1270	1200
Total number of points	4200	4500	3900	2100	3900	4200	2400	4100	2000	4300
IC Number	110	92	53	110	99	101	95	76	100	93
Plagioclase composition	An_{35}	An_{35}	An_{25}	An_{20}	An_{37}	An_{33}	An_{20}	An_{26}	An_{28}	An_{35}

Notes on field occurrence on next page.

TABLE IV

Comparative Chemical Compositions of Microcline and Biotite Gneiss and Various

Sedimentary and Igneous Rocks (Weight per cent)

Rock	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	H_2O^+	Total
Average microcline gneiss ($\bar{x}$)	69.2	15.8	1.9	1.8	0.5	2.9	3.4	4.5	0.2	0.2	100.4
Average biotite gneiss, this study	70.3	13.1	2.5	4.9	2.5	1.2	1.2	2.5	0.9	0.8	99.9
Average shale (Clarke, 1924)	58.1	15.4	4.0	2.5	2.4	3.1	1.3	3.2	0.7	5.0	
Average graywacke (Pettijohn, 1960)	66.7	13.5	1.6	3.5	2.1	2.5	2.9	2.0	0.6	2.4	
Average lithic arenite (Pettijohn, 1960	66.1	8.1	3.8	1.4	2.4	6.2	0.9	1.3	0.3	3.6	
Average arkose (Pettijohn, 1960)	77.1	8.7	1.5	0.7	0.5	2.7	1.5	2.8	0.3	0.9	
Average Russian platform sandstone (Pettijohn, 1960)	70.0	8.2	2.5	1.5	1.9	4.2	0.6	2.1	0.6		
Average Mississippi delta silt (Poldervaart, 1955)	74.7	10.3	3.5		1.4	2.2	1.5	2.3	0.6		
Average eugeosynclinal sandstone* (Middleton, 1960)	69 (71)	13 (14)	5.4 (3.6)		2.5 (2.2)	4.4 (2.7)	3.2 (3.1)	2.0 (1.8)			

* - Geometric average in parentheses

Note: Where figures for oxides are missing, information was not given in reference. In some analyses, ferrous and ferric oxides are combined. Some analyses were recalculated on a water-free basis.

TABLE II
(Continued)

Field Occurrence of Analyzed Specimens

#350C - Unaltered dump sample of microcline gneiss from mine near head of Silver Creek.

#472 - Unaltered dump sample of microcline gneiss from Montana Creek.

#623B - Outcrop sample of microcline gneiss from southeast slope of Arizona Mountain at 9800 feet.

#623A - Outcrop sample of pegmatite in microcline gneiss, same location as #623B.

#627 - Outcrop sample of microcline gneiss from southeast slope of Arizona Mountain at 10,100 feet.

#629 - Outcrop sample of microcline gneiss from southeast slope of Arizona Mountain at 9,500 feet.

#666 - Outcrop sample of microcline gneiss from east slope of Dakota Hill at 10,800 feet.

#683B - Outcrop sample of microcline gneiss from hill 3/4 mile southeast of Dakota Hill by BM 10596.

#697 - Outcrop sample of microcline gneiss from Silver Creek at 9,400 feet.

#704 - Outcrop sample of microcline gneiss from north part of Blackhawk Peak at 10,250 feet.